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PERFORMANCE EVALUATION OF A CENTRIFUGAL BLOWER OF AIR ASSISTED SPRAYER FOR ORCHARD PESTICIDE APPLICATION

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ABSTRACT

In air carrier sprayer, spray liquid is carried to the target by air. The volume of air required is equal to the volume of the tree for effective coverage. The centrifugal fan with a forward curved blade and blower casing was designed to deliver the air of 3 m^3/s for 35 hp tractor operated air assisted sprayer for orchard pesticide application on Mango orchard. The blade shape, blade inlet and outlet angle and blade inclination angles which have the best performance were considered. The keeping all other design parameter constant, three centrifugal impeller (fan) with 36, 40 and 44 number of blades was design and developed. The performance of the developed blower was evaluated tested at five blower speed in laboratory as per AMCA standard to know the best operating parameter for efficient and economical operation. The best performance was observed for Blower B with 40 blades and was selected for development of air assisted sprayer.

KEYWORDS: Centrifugal Blower, Blower Speed, Air Discharge, Air Pressure, Casing, Input Power, Blower Efficiency

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Original Article

INTRODUCTION

The deposition of spray droplets, requirement of air volume in air assisted spraying system and pesticide application rates are mainly influenced by canopy characteristics, like leaf area index and leaf area density. The average size of tractor available in India is 35 hp and present spraying systems are not suitable for 35 hp tractor. Considering the constraints of available power, canopy characteristics, canopy height of mango tree blanket application is not possible. The suitable alternative will be localized application by air-assisted system operated by 35 hp tractors. A centrifugal impeller with a forward curved blade impeller was designed for the required air velocity and volume to be suitable for used on air assisted sprayer for *Alphanso* Mango trees. Samson (1987) studied effect of blade number and outlet blade angle on blower performance. The rate of increase of flow rate decreases as the blade number increase from 24 to 30 still increased in blade number may reduce flow passage considerably to cause some resistance to the fluid flow. The 120^0 outlet blade angle, the reduced flow passing due to increase blade number to 30 was not affect much incases of the air flow. He also mentioned that selection of number of blade should be finalized at the cost of input power to the blower as well as discharge. Shah *et al.* (2003) carried out assessment of forward and backward curved radial tipped centrifugal fans. They observed that the pressure head generated by forward curve radial tipped centrifugal fan was higher than that for backward curved radial tipped centrifugal fan. At 50 % and 75 % damping conditions, efficiencies of backward curved radial tipped centrifugal fans were 93.9 % and 81 %, while that for forward curved radial tipped centrifugal fan, these values were 87.5% and 66 % respectively at 2800 rpm.

There was need to evaluate the performance of designed forward curved blade blower suitable for air assisted sprayer based on fundamental concepts to know the best operating parameter for efficient and economical operation.

MATERIALS AND METHODS

Impeller of blower consists of the vanes or blades mounted on the disc. This impeller is mounted on the hub which in turn is keyed to rotating shaft. The forward curved blade was selected for design as impellers have small and numerous blades with pronounced curvature and short chord length. The concave blade curvature faces the direction of rotation. It operates at relatively low speeds and pressure, which permits lighter construction of the impeller. The blower was designed to deliver the air at the rate of 3 m^3/s to be operated by 35 hp tractor at 2250 rpm. Though tractor is of 35 hp, after accounting for losses, the about 25 hp power is available for driving blower and pump of the air assisted sprayer. The centrifugal blower's impeller suitable for localized application of pesticide in mango orchard is designed as the dimensions obtained are given below and developed impellers are shown in Figure 1.

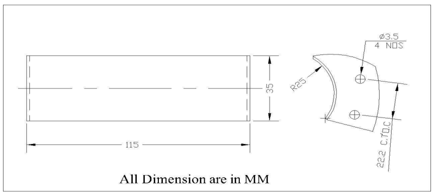

Figure 1: Schematic of Diagram of Blade of Impeller

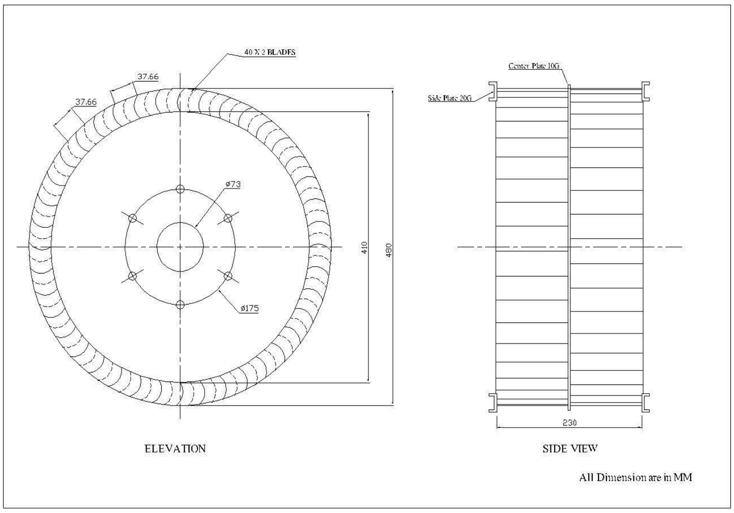

Figure 2: Schematic Diagram of impeller B of Centrifugal blower (40 blades)

The dimensions of designed impeller and casing are presented as below,

Impeller

Type: Centrifugal Impeller with forward curved blades

Inlet diameter: 410 mm

Outlet diameter: 480 mm

Width of impeller: 230 mm

Material : Stainless steel.

Blades

Blade inlet angle: 14^{0}

Blade outlet angle: 160^{0}

Width of blade: 35 mm

Length of blade: 115 mm (on one side) x 2

Number of blades: 36, 40 and 44 (single side)

Material: Stainless steel.

Blower Casing

Maximum diameter: 890 mm

Minimum diameter: 800 mm

Width of casing: 270 mm

Outlet size: 178 mm Ø

Casing Inlet size: 490 mm Ø and 400 mm Ø

Material: Fiber Reinforced plastic (FRP)

Thickness: 6 mm

The centrifugal blower's casing suitable for localized application of pesticide in mango orchard is designed and the dimensions obtained are presented Figure 3.

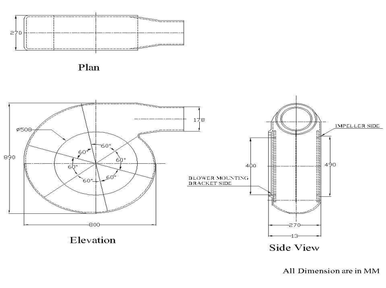

Figure 3: Schematic Diagram of Newly Developed Volute Type Centrifugal Blower Casing

Three impellers A, B, C were fabricated with different number of blades with same diameter. These impellers were operated in a casing of the same design. Number of blades and blower speeds are prime factors affecting performance of the blower. Air assisted sprayers and centrifugal blower are operated at 2000 to 2500 rpm as reported by Samson, 1987 and Unhale, 1989. The blade solidity and their spacing affects its performance. Three level of blade number 36, 40 and 44

were selected for the study. Thus to study the effect of blade number and speed of operation on blower performance various experiments were conducted. The experiment was conducted in the laboratory at 2050,2150,2250,2350 and 2450 rpm to know air velocity, air discharge, air pressure, power requirement,blower efficiency and performance index. The various test parameters for laboratory testing of blowers were taken as per AMCA (American Air Control Association) standard.

Measurement of Flow Parameters

The mean velocity head h_m is obtained from the pitot static tube measurements following tangential and log linear method. According to this method, at test section, cross section of air duct of wind tunnel is divided into four section having N points, amounting to 4 N observations. Taking V_1, V_2 V_N as the velocities obtained at these different points, the mean value is given as

$V_m = (K\sqrt{h_1} + K\sqrt{h_2} + \ldots.. + K\sqrt{h_n})/4\,N$

$K\sqrt{h_m} = K\sqrt{h}\,/4\,N$

$\sqrt{h_m} = \sqrt{h}\,/4\,N$

Knowing the values of mean velocity V_m and cross sectional area "A" of the test section, the discharge rate 'Q' can be given as

$Q = A\,V_m = A\,K\sqrt{h_m}$

One centimeter rise of water column amounts to pressure of 98.1 N/sq.m. The dynamic and static heads at test section are converted into respective pressure as,

Dynamic pressure (P_v) =dynamic head x 98.1, N/m^2

Static pressure (P_s) =Static head x 98.1, $N/\ m^2$.

Total pressure (P_t) $=P_v+P_s$, $N/\ m^2$

To determine the various output parameters at blower exit, the various losses in wind tunnel was considered. Loss of pressure between blower outlet and test section is given by

$P_L = f\,(L_1/D_h+L_2/D_h)\,P_v$

Where,

f=friction factor,

L_1=length between blower outlet and test section, m

D_h =equivalent hydraulic diameter at blower outlet, m

L_2 / D_h in above expression can be calculated by

$L_2 / D_h=15.04 / [1-26.65\,(Y/D)+184.6\,(Y/D)]^{1.83}$

Where,

Y=thickness of flow straightener, m;

L_2=equivalent length of flow straightner, m;

D=Diameter of test section, m (generally Y/D is 0.005)

P_v=dynamic pressure at test section, N/m^2

However, the friction factor f is given by

$f=0.14/R_e^{\ 0.17}$

And Reynolds's number is given by

$R_e = \rho_a V Dh / \mu$

Where V =velocity of air, m/s

ρ_a= desity of air, kg/m^3 and

μ = viscosity of air, which is generally taken as 1.85×10^{-5} kg s $/m^2$

The dynamic pressure at blower exit, P_{ve} is given by

$P_{ve}=P_v (A_t \rho_t / A_e \rho_e)^2$

Where,

A_t =cross sectional area at test section, m^2

A_e=cross sectional area at blower exit, m^2

ρ_t=air density at test section,kg/ m^3

ρ_e=air density at blower exit,kg/ m^3

Generally, ρ_t and ρ_e are considered equal.

Hence, $P_{ve}=P_v(A_t/A_e)^2$

The total pressure at blower exit will exceed that of the test section by friction loss. Thus, total pressure is

$P_{te}=P_t+P_L$

Air velocity at blower exit was calculated from equation of continuity,

$V_e=V_t(D_t/D_e)^2$

Input power to motor can be found by

$P=\sqrt{3}\, E\, I \cos\varphi$

Where,

P = input power to motor, watt

E = input voltage to motor, V

I = input current to motor, amp and

$\cos\varphi$ = power factor.

The efficiency of motor, η_m varies with input load. The output power of motor, P_o is given as

$P_o = P\,\eta_m = \sqrt{3}\,E\,I\cos\varphi.\,\eta_m$

Input Power to Blower is the power of motor minus transmission losses (K).It can be expressed as

$P_{ib} = P_o(1-K) = \eta_m\sqrt{3}\,E\,I\cos\varphi\,(1-K)$

Generally the value of K is taken as 0.02. Knowing the discharge rate Q and Total pressure P_{te}, the output power can be calculated as ;

$P_{ob} = Q\,P_{te}$

Where,

P_{ob}=output power, watt

P_{te} = total pressure, N/ m^2 and

Q=discharge rate, m^3/s

Efficiency of the blower is calculated as,

η_b (%)=output power of blower / input power of blower

$= Q\,P_{te} / \eta_m\sqrt{3}\,E\,I\cos\varphi\,(1-K)$

Performance Coefficients is given as,

Power Coefficient, $\Lambda_p = P_i/N^3 D_2^5$

Laboratory Set Up for testing of Centrifugal Blower and Test Procedure Adopted

All the experiments were conducted following AMCA (American Air Moving and Control Association) standard. The laboratory test set up consisted of Blower Assembly, Frame to support blower, Wind tunnel assembly as per AMCA Standard, Prime mover (electric motor), Transmission assembly, Power measuring instruments, Speed measuring instruments and Temperature and RH measuring instruments. The wind tunnel assembly was fabricated as per AMCA standard specifications. It consisted of transition section, flow straightener and tunnel. The detail of wind tunnel assembly for developed blower testing is shown in Figure 4. The traverse points of wind tunnel assembly are shown Figure 5. A complete set up for testing the performance of the centrifugal blower is shown in Figure 6.

The following procedure was adopted for evaluation of performance of centrifugal blower in the laboratory. Experiments were conducted as per AMCA standard.

- Impeller A was fitted in casing connected to wind tunnel assembly. Air screen was fixed to the inlet hole of casing. It was ensured that the direction of rotation was in forward direction.
- With proper combination of chain sprockets of power transmission system, blower speed was fixed to 2050 rpm.
- Pitot tube was fixed at one of point of the twenty traverse points and connected to the manometer.

- Temperature, RH, dry bulb temperature and wet bulb temperature was recorded at the test location of the laboratory.
- Electric motor was started and current was stabilized.
- The dynamic head was measured at test section by connecting both end of Pitot tube to the manometer. The static head at test section was measured by connecting static head section of Pitot tube to the manometer. Another dynamic head end was kept open to the atmosphere.
- Current and Voltage consumed by the electric motor was measured by Ammeter and Voltmeter.
- The procedure was repeated from step 3 to 7 for all 20 traverse point of wind tunnel.
- The procedure was repeated from3 to 8 for other speed of blower.
- Steps from 1 to 9 were repeated for Impeller B and Impeller C.
- Three replications were conducted for all above experiments.
- Results of the experiments were analyzed.

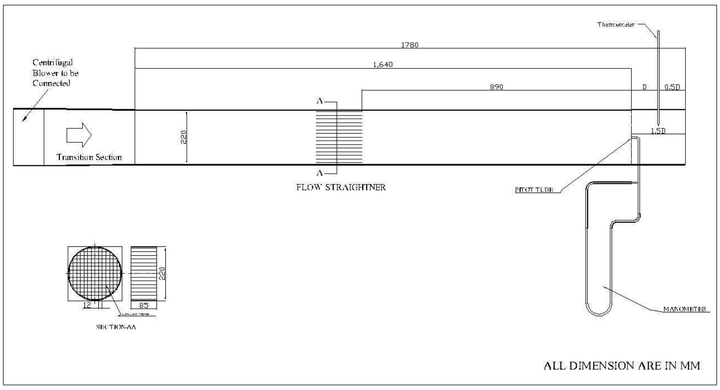

Figure 4: Details of Wind Tunnel Used For Centrifugal Blower Testing

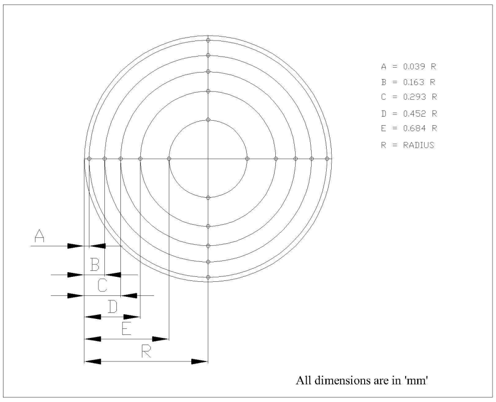

Figure 5: Traverse Points of Wind Tunnel

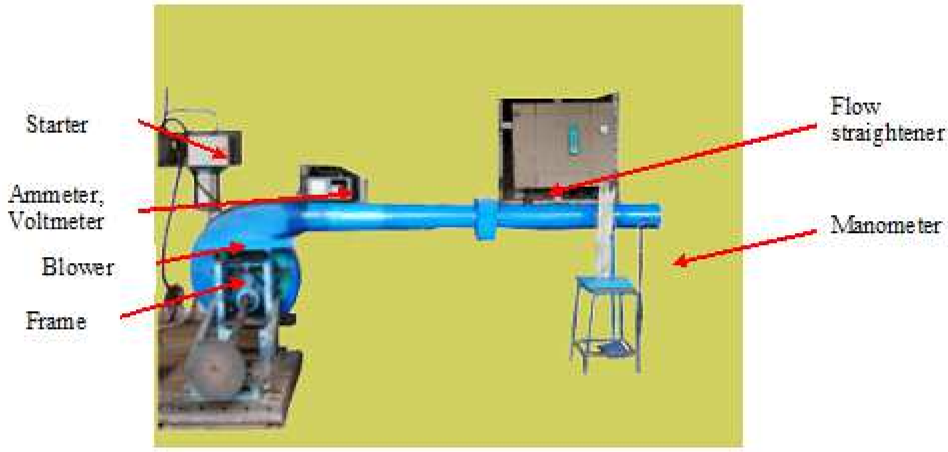

Figure 6: A Complete Laboratory Test Set Up For Testing the Performance of Centrifugal Blower

The results obtained were analyzed statistically to know the effect of number of blades and speed of operation on and combined effect of number of blades and speed of operation on blower performance significance.

RESULTS AND DISCUSSIONS

Centrifugal blower with 36 (A), 40 (B) and 44 (C) forward curved blades with same diameter and involute casing design was fabricated for air assisted sprayer. These were tested in the laboratory following AMCA standard and procedure. The performance parameters of Blower A, B and C at various blower speed are presented in Table 1. The result indicated that the air velocity at blower exit varied from 97.83 m/s to109.94 m/s from 2050 rpm to 2450 rpm for Blower A, from 97.27 m/s to 112.84 m/s from 2050 rpm to 2450 rpm for Blower B and from 102.13 m/s to 122.57 m/s from 2050 rpm to 2450 rpm for Blower C. The air discharge varied from 2.44 m^3/s to 2.74 m^3/s, 2.42 m^3/s to 2.80 m^3/s and 2.54 m^3/s to 3.05 m^3/s from 2050 rpm to 2450 rpm for Blower A, Blower B and Blower C respectively. Both air velocity and air discharge increased with increased in blower speed due to increased peripheral speed of blade of impeller at blower exit. Higher air velocity and air discharged was observed for Blower C compared to Blower A and B at five blower speeds (Figure 7).The percentage increase for Blower A, B and C was 12.32 %, 16.00 % and 20.00 % at 2050 rpm to 2450 rpm blower speed respectively.

Table 1: Performance of Developed Centrifugal Blower Different Blower Speeds

S.No	Performance parameters	Blower Speed, rpm				
		2050	2150	2250	2350	2450
Blower A						
1	Mean air velocity, m/s	97.83	100.96	102.76	105.46	109.94
2	Air discharge, m^3/s	2.44	2.51	2.55	2.62	2.74
3	Total pressure, N/m^2	3282.06	3463.72	3591.22	3787.03	4173.36
4	Input power to blower, kW	11.8	12.53	13.80	15.30	17.88
5	Efficiency of blower, %	67.88	69.3	66.37	64.83	63.92
6	Power coefficient	6.48	6.09	5.59	5.32	5.40
Blower B						
1	Mean air velocity, m/s	97.27	102.68	108.43	110.37	112.84
2	Air discharge, m^3/s	2.42	2.56	2.70	2.75	2.80
3	Total pressure, N/m^2	3234.61	3618.43	4011.28	4165.66	4300.61
4	Input power to blower, kW	11.95	13.08	15.11	16.79	18.40
5	Efficiency of blower, %	65.52	70.79	71.67	68.25	65.43

Table 1: Contd.,						
6	Power coefficient	6.31	6.50	6.58	6.15	5.65
Blower C						
1	Mean air velocity, m/s	102.13	104.42	111.21	116.84	122.57
2	Air discharge, m^3/s	2.54	2.60	2.77	2.90	3.05
3	Total pressure, N/m^2	3556.16	3721.60	4209.91	4603.94	5132.08
4	Input power to blower, kW	14.10	14.67	17.27	18.95	23.04
5	Efficiency of blower, %	64.05	65.98	67.50	70.44	67.92
6	Power coefficient	7.34	6.84	7.21	7.15	7.56

RH: 60-70 %, Temperature: 25 -30 ^{0}C, Replications: 3

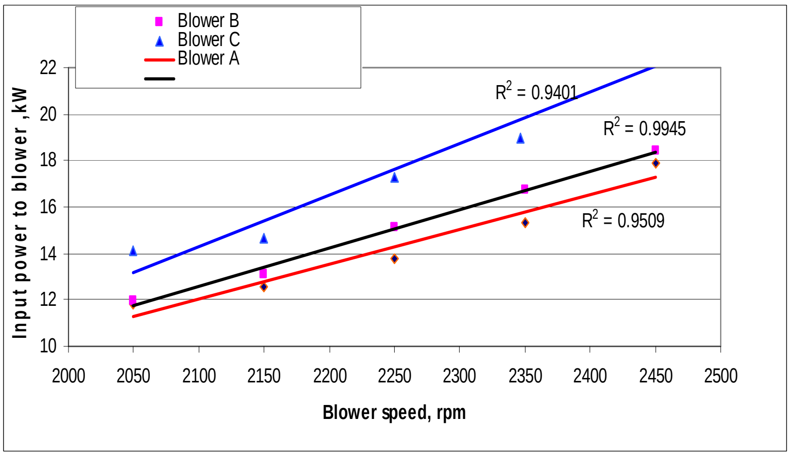

Figure 7: Effect of Blower Speed on Input Power to Blowers

The data indicated that blower total air pressure at blower exit varied from 3282.06 to 4137.36 $N/m^{2,}$ 3234.61 to 4300.61 N/m^2 and 3556.16 to 5132.08 N/m^2 from blower speed 2050 to 2450 rpm for Blower A, Blower B and Blower C respectively. The per cent increase for blower A, B and C was 26.05 %, 32.95 % and 44.5 % at 2050 rpm to 2450 rpm blower speed respectively. This justifies that for the higher pressure head requirement, the forward curved blade centrifugal blower can be selected.

The result of test indicated that input power to blower varied from 11.80 kW to17.88 kW, 11.95 kW to 18.40 kW and 14.10 kW to 23.04 kW from 2050 rpm at 2450 rpm for Blower A, B and C respectively. The percentage increase in input power to Blower A, B and C was 51.52 %, 53.97 % and 63.40 % at 2050 rpm to 2450 rpm blower speed respectively.

The effect of speed on blower efficiency is shown in Figure 7.The results revealed that maximum blower efficiency of 69.3 % at 2150 rpm and minimum of 63.92 % at 2450 rpm for Blower A, maximum blower efficiency 71.67 % at 2250 rpm and minimum of 65.43 % at 2450 rpm for Blower B and maximum blower efficiency 70.44 % at 2350 rpm and minimum of 64.05 % at 2450 rpm for Blower C respectively were obtained. Results show that for blower A, the blower efficiency decreased with increase in blower speed. This may be due to more spacing between blades which causes frictional losses of the impeller and volumetric losses in lateral gap. This might have reduces the blower efficiency as blower speed increased. For blower B, as the blower speed increased from 2050 rpm to 2250 rpm, the blower efficiency increased and thereafter decreased with increase in blower speed. This may be due to decrease in the static pressure at the tongue of casing as air discharge increased. Further as number of blade increased from 36 to 40, the static pressure increased when air discharge increased. Similar results were reported by Vibhakar (2012). The blower efficiency of Blower C increased with increase in blower speed and it was noticed that the maximum efficiency of Blower C was shifted to

higher blower speed. This may be due to more number of blades in Blower C. As number of blade increases the flow within the blade get more kinetic energy and reduces the flow separation effect at tongue of casing. Also volute with smaller outlet create tendency of retardation of flow.

Figure 8 shows the trend of second degree polynomial for blower efficiency. Statistically the value of Coefficient of determination, R^2 was found to be non-significant.

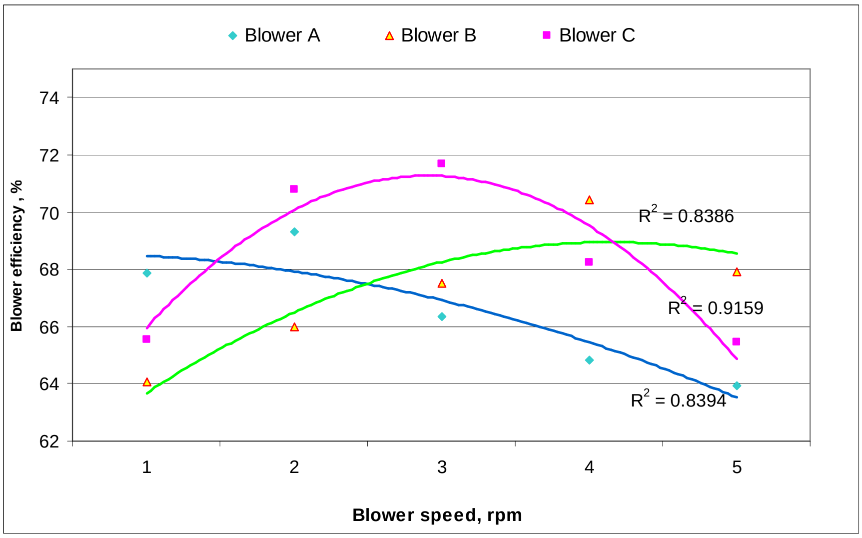

Figure 8: Effect of Blower on Blower Efficiency of Blowers

The test revealed that maximum and minimum blower efficiency of 69.3 % at 2150 rpm and 63.92 % at 2450 rpm, 71.67 % at 2250 rpm and 65.43 % at 2450 rpm and 70.44 % at 2350 rpm and 64.05 % at 2450 rpm for Blower A, B and C respectively. This confirms that the forward curved blade centrifugal blower efficiency is lower as compared to 80-95 % efficiency in backward curved blade (Shah *et. al,* 2003).

Effect of number of blades and speed of rotation and their interaction on air discharge

Table 2 shows the analysis of variance (ANOVA).It indicate that effect of number of blades and speed of operation on air discharge by blower is significant at 1 % level of probability. Also combined effect of number of blades and speed of operation is significant at 1 % level of probability. The mean value indicate mean air discharge of 2.57 m^3/s for blower A, 2.64 m^3/s for Blower B and 2.77 m^3/s for blower C respectively.

Table 2: ANOVA Table for Effect of Number of Blades and Speed on Air Discharge, M^3/S

SN.	Source	DF	SS	MS	F
1.	No of blades(A)	2	0.304253	0.152127	233.642**
2.	Blower speed(B)	4	0.895498	0.223874	343.834**
3.	A x B	8	0.0844356	0.0105544	16.210**
4.	Error	30	0.0195333	0.000651111	

A= Number of Blades, B= Speed of rotation of impeller, rpm, CV = 0.9588

** Significant at 1 % level of probability

Effect of Number of Blades and Speed of Rotation and their Interaction on Blower Efficiency

Table 3 shows the result of analysis of variance (ANOVA).It indicate that effect of number of blades and speed of operation on blower efficiency to blower is significant at 1 % level of probability. Also combined effect of number of

blades and speed of operation is significant at 1 % level of probability. The mean blower efficiency of 67.09 % for blower A, 68.05 % for blower B and 67.17 for blower C respectively was observed.

Table 3: ANOVA Table for Effect of Number of Blades and Speed on Blower Efficiency, %

SN.	Source	DF	SS	MS	F
1.	No of blades(a)	2	8.36544	4.18272	67.340**
2.	Blower speed(b)	4	27.4321	6.85803	110.412**
3.	A x b	8	402.249	50.2812	809.507**
4.	Error	30	1.8634	0.0621133	

A= Number of Blades, B= Speed of rotation of impeller, rpm, CV = 0.3696

** Significant at 1 % level of probability

Effect of Number of Blades and Speed of Rotation and their Interaction on Power Coefficient

Table 4 shows the result of analysis of variance (ANOVA).It indicate that effect of number of blades and speed of operation on power coefficient is significant at 1 % level of probability. Also combined effect of number of blades and speed of operation is significant at 1 % level of probability. The mean power coefficient was 5.78 for blower a, 6.24 for blower B and 7.22 for Blower C was observed respectively.

Table 4: ANOVA Table for Effect of Number of Blades and Speed on Power Coefficient

SN.	SOURCE	DF	SS	MS	F
1.	No of blades (A)	2	16.3145	8.15726	832.373**
2.	Blower speed (B)	4	1.62892	0.40723	41.554**
3.	A x B	8	3.77648	0.47206	48.169**
4.	Error	30	0.294	0.0098	

A= Number of Blades, B= Speed of rotation of impeller, rpm, CV = 1.5441

** Significant at 1 % level of probability

The analysis of results also revealed that Blower B and C follows fan law indicating better performance. The Blower B gives best design result and are giving at par blower output within available power. The selection of number of blade should be finalized at the cost of input power to the blower as well as discharge requirement.

CONCLUSIONS

The following conclusions were drawn from performance evaluation of centrifugal blower,

- The air discharge, input power to blower and blower efficiency ranged from 2.42 to 2.80 m3/s, 11.95 kW to 18.40 kW and 65.43 to 71.67 % respectively for blower with 40 blades.
- 2.The mean air discharge of 2.57 m^3/s, 2.64 m^3/s and 2.77 m^3/s, mean blower efficiency of 67.09 %, 68.05 % and 67.17 and mean power coefficient was 5.78, 6.24 and 7.22 for Blower A,B and C respectively were observed.
- As number of blade increased from 36 to 40, the static pressure increased when air discharge increased. As number of blade increases the flow within the blade get more kinetic energy and reduces the flow separation effect at tongue of casing.
- Based on the performance of the blowers A, B and C at various blower speeds, statistical analysis of the results and requirement of the air assisted sprayer, the Blower B was selected for air assisted sprayer to be operated at 2250 rpm which meets requirement.

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